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Formation and use of coal combustion residues from three types of power plants burning Illinois coals

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Abstract

Coal, ash, and limestone samples from a fluidized bed combustion (FBC) plant, a pulverized coal combustion (PC) plant, and a cyclone (CYC) plant in Illinois were analyzed to determine the combustion behavior of mineral matter, and to propose beneficial uses for the power plant ashes. Pyrite and marcasite in coal were converted during combustion to glass, hematite and magnetite. Calcite was converted to lime and anhydrite. The clay minerals were altered to mullite and glass. Quartz was partially altered to glass. Trace elements in coal were partially mobilized during combustion and, as a result, emitted into the atmosphere or adsorbed on fly ash or on hardware on the cool side of the power plants. Overall, the mobilities of 15 trace elements investigated were lower at the FBC plant than at the other plants. Only F and Mn at the FBC plant, P, Hg, and Se at the PC plant and Be, F, Hg, and Se at the CYC plant had over 50% of their concentrations mobilized. Se and Ge could be commercially recovered from some of the combustion ashes. The FBC ashes could be used as acid neutralizing agents in agriculture and waste treatment, and to produce sulfate fertilizers, gypsum wall boards, concrete, and cement. The PC and CYC fly ashes can potentially be used in the production of cement, concrete, ceramics, and zeolites. The PC and CYC bottom ashes could be used in stabilized road bases, as frits in roof shingles, and perhaps in manufacturing amber glass.

Keywords: Coal combustion residues; Combustion at power plants; Illinois coals; Mineral matter

1. Introduction

Inorganic matter in coal is converted to coal combustion residues (CCRs) at coal-fired power plants. Virtually every economical use of coal depends in part on the amount and variety of its inorganic matter. Inorganic matter in coal can be the source of deleterious pollutants and corrosive elements, but it can also be a source of useful by-products.

Sixteen elements in coal (As, Be, Cd, Cl, Co, Cr, F, Hg, Mn, Ni, P, Pb, Sb, Se, Th, U) are among the 189 hazardous air pollutants (HAPs) mentioned in the 1990 Clean Air Act Amendments (CAAA) [1]. Partitioning of these and other elements among the CCRs and flue gas is highly variable [2–5] because of the variations in the types and operational conditions of combustion units, the characteristics of coal, and the modes of occurrences of the elements in the coal. Difficulties in obtaining representative samples, as well as analytical errors, contribute to the variability of data on the retention or emission of potentially toxic elements from the power plants. The HAPs provisions of the CAAA presently focus on municipal incinerators and petrochemical and metal industries. A risk analysis by the US Environmental Protection Agency concluded that, at present, only Hg emission from coal-fired electrical utilities requires further investigation [6]. A final regulation on Hg emission is expected by the end of 2004.

US utilities annually generate 107 million tons of CCRs, 59% of which is fly ash (Fig. 1). Beneficial uses of CCRs include soil and mine waste treatments, admixtures in cement and concrete, making bricks and other ceramic products, fill materials in civil engineering projects, and extraction of valuable materials [8–17]. However, only about 31% of all the CCR generated in the US is used commercially (Fig. 1); the remainder is discarded in landfills or in coal mines.

This study evaluated chemical, mineralogical, and microscopic characteristics of feed coals and CCRs from three types of electrical power plants in Illinois to determine (1) the combustion behavior of minerals, (2) the fate of 15 elements (As, Be, Cd, Co, Cr, F, Hg, Mn, Ni, Pb, P, Sb, Se, Th, and U) of environmental concern, and (3) the potential economic value of the CCRs from the power plants.

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Table 4
Concentrations of 15 HAPs, Ge, Zn, and Ti in earth's crust, shales, soils, and CCRs, and the enrichments factors for the same elements in the CCRs

	As	Ba	Cd	Co	Cr	F	Hg	Mn	Ni	P	Pb	Sb	Se	Th	U	Ge	Zn	Ti
Concentrations (mg/kg)[a]																		
Crustal average	1	3	0.2	25	100	544	0.08	950	75	1000	13	0.2	0.05	7.2	1.8	1.5	70	4400
Shale average	13	3	0.3	19	90	800	0.18	850	68	700	25	1.5	0.5	12	3.7	2.0	120	4600
Soil average	7	0.9	0.6	9	55	300	0.10	550	20	500	19	0.7	0.4	9	2.7	1.0	70	3000
FBC — fly ash	6.1	6	2.5	12.3	75	53	0.25	620	66	567	14.1	1.3	14.4	5.6	7.1	13	193	1980
— bottom ash	4	0.5	0.6	4.3	35	48	0.01	310	14	480	4.8	0.8	0.5	1.9	4.0	4	73	660
PC — fly ash	34	9	4.9	20	175	67	0.10	468	77	524	49	7.9	7.4	12.6	16.8	114	306	5460
— bottom ash	3	9	0.5	22	136	5	0.005	468	85	262	10	2.2	2.2	10.4	12.5	20	133	3900
CYC — fly ash	51	14	11.5	24.2	227	230	0.73	310	173	742	89.7	13.6	43.3	14.6	21.7	200	962	6114
— bottom ash	1.2	5.5	0.48	20.2	112	15	0.02	542	70	524	2.7	1.1	2.1	11.3	11.1	9	97	4016
Enrichment factors[b]																		
FBC fly ash with respect																		
to crust	6.1	2.0	13	0.5	0.8	0.1	3.1	0.7	0.9	0.6	1.1	6.5	288	0.8	3.9	8.7	2.8	0.5
to shale	0.5	2.0	8.3	0.6	0.8	0.1	1.4	0.7	1.0	0.8	0.6	0.9	29	0.5	1.9	6.5	1.6	0.4
to soil	0.9	6.7	4.2	1.4	1.4	0.2	2.5	1.1	3.3	1.1	0.7	1.9	36	0.6	2.6	13	2.8	0.7
FBC bottom ash with respect																		
to crust	4.0	0.2	3.0	0.2	0.4	0.1	0.1	0.3	0.2	0.5	0.4	4.0	10	0.3	2.2	2.7	1.0	0.2
to shale	0.3	0.2	2.0	0.2	0.4	0.1	0.1	0.4	0.2	0.7	0.2	0.5	1.0	0.2	1.1	2.0	0.6	0.1
to soil	0.6	0.6	1.0	0.5	0.6	0.2	0.1	0.6	0.7	1.0	0.3	1.1	1.3	0.2	1.5	4.0	1.0	0.2
PC fly ash with respect																		
to crust	34	3.0	25	0.8	1.8	0.1	1.3	0.5	1.0	0.5	3.8	40	148	1.8	9.3	76	4.4	1.2
to shale	2.6	3.0	16	1.1	1.9	0.1	0.6	0.6	1.1	0.7	2.0	5.3	15	1.1	4.5	57	2.6	1.2
to soil	4.9	10	8.2	2.2	3.2	0.2	1.0	0.9	3.9	1.0	2.6	11	19	1.4	6.2	114	4.4	1.8
PC bottom ash with respect																		
to crust	3.0	3.0	2.5	0.9	1.4	0.0	0.1	0.5	1.1	0.3	0.8	11	44	1.4	6.9	13	1.9	0.9
to shale	0.2	3.0	1.7	1.2	1.5	0.0	0.0	0.6	1.3	0.4	0.4	1.5	4.4	0.9	3.4	10	1.1	0.8
to soil	0.4	10	0.8	2.4	2.5	0.0	0.1	0.9	4.3	0.5	0.5	3.1	5.5	1.2	4.6	20	1.9	1.3
CYC fly ash with respect																		
to crust	51	4.7	58	1.0	2.3	0.4	9.1	0.3	2.3	0.7	6.9	68	866	2.0	12	133	14	1.4
to shale	3.9	4.7	38	1.3	2.5	0.3	4.1	0.4	2.5	1.1	3.6	9.1	87	1.2	5.9	100	8.0	1.3
to soil	7.2	16	19	2.7	4.1	0.8	7.3	0.6	8.7	1.5	4.7	19	108	1.6	8.0	200	14	2.0
CYC bottom ash with respect																		
to crust	1.2	1.8	2.4	0.8	1.1	0.0	0.3	0.6	0.9	0.5	0.2	5.5	42	1.6	6.2	6.0	1.4	0.9
to shale	0.1	1.8	1.6	1.1	1.2	0.0	0.1	0.6	1.0	0.7	0.1	0.7	4.2	0.9	3.0	4.5	0.8	0.9
to soil	0.2	6.1	0.8	2.2	2.0	0.1	0.2	1.0	3.5	1.0	0.1	1.6	5.3	1.3	4.1	9.0	1.4	1.3

[a] The values for Earth's crust, shale, and soils were compiled from Swaine [2], Clarke and Sloss [3], Drever [44], Gluskoter et al. [45], and Krauskopf [46].
[b] Enrichment factors of greater than 10 are shown in bold.